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FPL-410

Use of Oak in Linerboards

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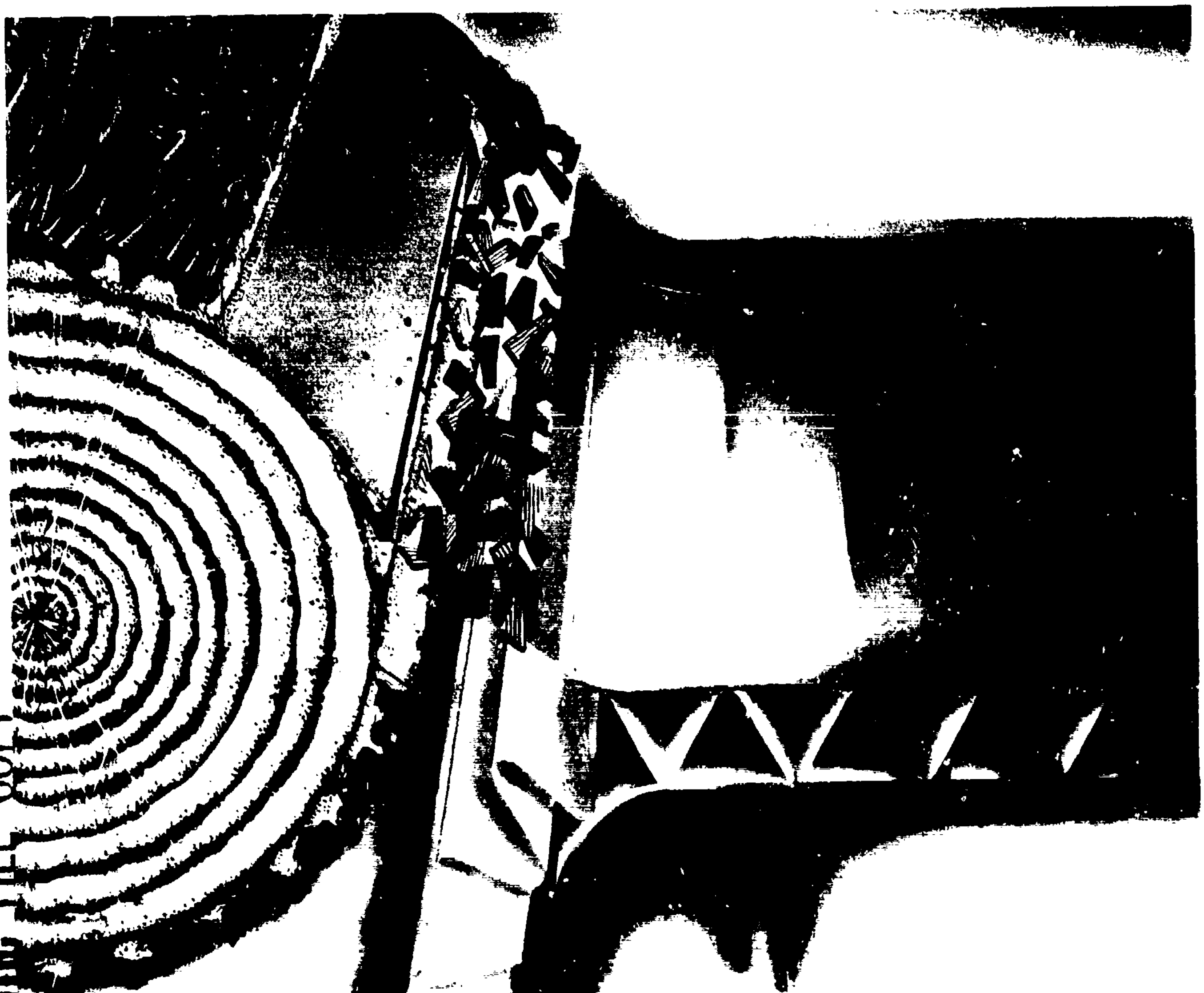

Abstract

In order to alleviate the increasing demand for softwoods, oak and pine pulps in varying ratios were investigated for linerboard use in corrugated containers. It was found that oak could be used in significant amounts in linerboard stock and, thus, provide an outlet for this currently underutilized species. Upon evaluating the combined boards and assembled containers it appeared that, when properly fabricated, at least 25 percent oak could be included and still satisfy today's required carrier rules. Considerably higher percentage of oak could be tolerated based on actual box performance despite somewhat lower combined board burst values. Score-line fracturing for boards of any oak-pine ratio can be eliminated by proper adjustment of scorewheel clearance and board moisture content.

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Use of Oak in Linerboards

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Introduction

While statistics from various sources have documented an increasing pressure on the supply of virgin softwood for corrugated fiberboard production, the increasing supply of hardwoods, particularly oak, has been recognized for many years *(4)*.[2] The Forest Products Laboratory (FPL) has often directed its research towards the increased use of oak, with much of this effort aimed at the corrugating medium *(2, 3, 5, 8, 9, 11)*. Today, medium is predominantly hardwood neutral sulfite semichemical (NSSC) pulp, often supplemented with recycled fiber. Very little hardwood, however, is used in linerboard.

Once the hardwoods, including oak, were established as the primary furnish for medium, it became apparent that their use as a linerboard pulp source would also be desirable. Previous work on mixed Colombian hardwoods *(6)* demonstrated that hardwood kraft pulp (85 pct) plus northern pine kraft (15 pct) could give a sufficiently high burst so as to be acceptable, although at a sacrifice in tear. A primary objection to the majority of the work in this area centered around the lack of actual performance data on boxes. However, in 1960 Fahey and Setterholm *(7)* examined the effect of adding sweetgum kraft or sweetgum NSSC pulp to pine kraft pulp for use in linerboards. The resulting liners were converted into combined board, then boxes. The sweetgum kraft was far superior to the NSSC pulp, and the satisfactory use of up to 25 percent sweetgum was demonstrated. In 1976 Worster and Bartels *(12)* examined the combined pulping of hardwood and softwood versus separate pulping with subsequent blending. Separate pulping was confirmed superior.

Considering the limited use of hardwoods in linerboard, together with the need to extend our resources, it seemed appropriate to reexamine the question of how much hardwood, specifically oak, could be satisfactorily included in linerboard. Thus, this study was undertaken to determine the basic behavior of pine and oak pulp mixtures in linerboard, with specific attention given to box performance criteria including scoring and impact behavior.

Experimental Procedures

Wood Procurement and Processing

One cord of freshly cut loblolly pine *(Pinus taeda L.)* and one cord of freshly cut southern red oak *(Quercus falcata Michx.)* were obtained from the vicinity of Athens, Ga. Upon receipt at FPL, these logs were hand-peeled, converted into chips in a four-knife, Carthage chipper, screened and stored in a cold room until needed for the individual digestions. The nominal length of the loblolly pine chips was 16 mm (5/8 in.) and of the red oak chips, 13 mm (1/2 in.).

Kraft Pulping

Pilot-scale digestions of loblolly pine and of oak were made in a 400-liter (14-ft^3) digester. Conditions listed in footnotes of table 1 were chosen to produce a pine pulp with a Kappa number of 75 and an oak pulp with a Kappa number of 15, as determined by TAPPI Method T 236. At the end of both the pine and oak digestions, the digesters were blown. The resulting pulps were washed, screened through a 12-cut flat screen, dewatered, crumbed, and then stored in a cold room until needed for papermaking trials.

Representative samples of both the pine and the oak pulps were treated for strength development in a Valley beater, and converted into handsheets. The properties of these handsheets are given in table 1.

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Italicized numbers in parentheses refer to literature cited at end of this report.

Table 1.—Properties of handsheets made from experimental pulps used in linerboards[1]

	Loblolly pine kraft pulp[2]				Southern red oak kraft pulp[3]			
Freeness (Can. Stand.) (ml)	600	500	400	300	600	500	400	300
Beating time (min)	44	54	62	69	9	16	22	26
Burst factor	72	76	77	78	38	53	61	65
Tear factor	163	156	152	150	136	134	130	125
Breaking length (m)	9,400	9,600	9,700	9,700	7,500	9,300	10,000	10,400
Density (kg/m³)	610	630	650	660	590	630	660	680

[1] Tested according to TAPPI methods.
[2] Digestions 14-4663 through 14-4676. Conditions used were: 16 pct active alkali, 25 pct sulfidity, 4 to 1 water-to-wood ratio, 90 min from 80° to 170° C, and 40 min at 170° C. Composite pulp Kappa number was 75.
[3] Digestions 14-4638 through 14-4647. Conditions used were: 16 pct active alkali, 25 pct sulfidity, 3.5 to 1 water-to-wood ratio, 60 min from 80° to 170° C, and 90 min at 170° C. Composite pulp Kappa number was 15.

Papermaking

The kraft pulps were converted into 205-gram-per-square-meter (42 lb/1000 ft²) linerboard on the FPL experimental paper machine. Single-ply boards were made from 100 percent pine kraft and 100 percent oak kraft pulp, refined in each case to about 530 ml Canadian Standard freeness and from 25-75, 50-50, and 75-25 percent blends of the two pulps. For the blends the pine pulp was refined to 600-650 ml and mixed with the oak pulp which had been refined to 250-300 ml. In addition, a two-ply board was made with pine kraft pulp (refined to 600 ml) in the base ply and oak kraft pulp (refined to 350 ml) as the top ply. The top ply, constituting 25 percent of the total board weight, was applied in a secondary headbox. All of the refining was accomplished with a high-angle conical refiner. The pulp furnishes had 0.2 percent rosin size added, with the stock pH maintained at about 5.0 on the paper machine by the addition of an alum solution. The paperboard properties were determined by standard TAPPI test procedures and are given in table 2.[3]

[3] Expressed in SI units. Appendix I contains corresponding tables in English units.

Table 2.—Physical properties of oak-pine linerboards[1]

Machine run No.	Linerboard content		Basis weight	Density	Burst	Tear		Tensile strength		Tensile modulus of elasticity		Folds		Ring crush	
	Oak	Pine				Machine direction	Cross-machine direction	Machine direction	Cross-machine direction	Machine direction	Cross machine direction	Machine direction	Cross-machine direction	Machine direction	Cross-machine direction
	Pct		g/m²	kg/m³	kPa	mN		MPa		GPa		Double folds		N	
						SINGLE-PLY LINERBOARDS									
7210	0	100	207	640	704	3,360	3,560	51.1	24.7	4.70	2.36	1,616	953	570	449
7211	25	75	206	660	725	3,210	3,420	47.9	26.3	5.03	2.52	1,225	762	538	414
7212	50	50	206	680	743	2,930	2,990	50.4	26.7	4.84	2.59	1,011	753	543	418
7215	75	25	205	690	727	2,530	2,800	49.0	29.1	5.73	3.03	560	480	570	418
7213	100	0	206	690	560	1,920	2,060	43.1	25.6	5.14	2.76	201	92	449	374
						TWO-PLY LINERBOARD									
7214[2]	25	75	208	680	707	3,080	3,570	52.9	29.4	5.48	2.66	1,434	1,102	574	456

[1] See Appendix I for English equivalents.
[2] Oak only in top ply; pine only in bottom ply.

Table 3.—Physical properties of the combined board[1] [2]

Combined[3] board No.	Linerboard content		Basis weight		Burst		Flat crush		Pin adhesion				Short column compression						Flexural stiffness[4]			
									Single-face side		Double-back side		27° C, 30 percent relative humidity		23° C, 50 percent relative humidity		27° C, 90 percent relative humidity		Parallel-to-length		Perpendicular-to length	
	Oak	Pine																				
	— Pct —		g/m²	COV[5]	kPa	COV	kPa	COV	N/m	COV	N/m	COV	kN/m	COV	kN/m	COV	kN/m	COV	N•m	COV	N•m	COV
									SINGLE-PLY LINERBOARDS													
678	0	100	621	0.8	1,510	9.4	186	6.3	690	5.3	802	7.6	10.98	7.0	9.46	5.7	4.59	3.1	11.9	4.4	20.6	8.6
705	25	75	625	0.6	1,500	6.9	205	3.7	667	8.5	802	5.1	10.47	4.3	9.86	6.7	4.03	4.2	12.9	5.2	23.0	8.2
679	50	50	606	0.6	1,340	9.1	186	3.2	683	5.4	869	4.7	10.60	4.2	9.44	5.8	4.59	1.8	12.5	6.5	25.4	14.3
680	75	75	604	0.9	1,280	5.5	183	6.8	669	6.2	844	7.9	10.54	1.8	9.56	5.6	4.73	3.2	13.2	3.7	25.3	13.7
681	100	0	600	1.1	1,020	8.8	192	3.2	664	2.9	772	6.8	9.77	2.6	8.72	5.3	4.46	2.8	12.8	6.0	24.2	18.8
									TWO-PLY LINERBOARD													
682[6]	25	75	642	1.2	1,540	8.4	191	3.7	702	6.1	844	9.5	11.64	4.0	10.02	7.0	4.99	3.3	13.2	4.1	23.5	12.5

[1] All boards conditioned and tested at 23° C, 50 percent relative humidity except where noted.
[2] See Appendix I for English unit equivalents.
[3] All mediums were commercial 127 g/m² NSSC board.
[4] Four-point bending; flutes parallel or perpendicular to sample length; 5 samples single-face up and 5 samples single-face down.
[5] COV = coefficient of variation (=) percent.
[6] Oak only in top ply; pine only in bottom ply.

Combined Board and Box Fabrication

Each of the linerboards was combined with a commercial 127-gram-per-square-meter (26 lb/1000 ft²) NSSC medium in the Laboratory's 500-mm (20-in.) A-flute singlefacer using a conventional starch adhesive. Singlefaced board was cut into 1.2-m (4-ft) lengths and double-backed. Representative boards were selected at uniform intervals from throughout each run, then conditioned and evaluated according to TAPPI procedures. Two hundred-mm (8-in.)-high regular slotted container (RSC) boxes were prepared for top-to-bottom compression and 90-mm (3-1/2-in.)-high boxes with twelve 454-gram (1-lb) can loads were used for edgewise impact evaluation. The properties are given in tables 3,[3] 4[3] and 5.

Additional boards were set aside for cyclic humidity evaluation and performance testing *(1)*, the results of which will be reported upon completion of that study.

Discussion

Paperboard Properties

Table 2 shows the paperboards with the different oak and pine blends having bursting strengths equivalent to the all-pine board. Only the 100 percent oak board had a burst value of less than 690 kPa (100 points). Cross machine tensile strength and modulus of elasticity were higher for boards made with the blends than with 100 percent pine pulp, and the board with 75 percent oak had considerably higher values than the other two boards made with the lower oak contents. The combined freeness of this furnish, however, was somewhat lower than for the other blends and for the all-pine furnish, which may account for the better properties. The ring crush strength was changed slightly by the oak addition to the pine. As the oak content increased, visual examination showed better surface characteristics and formation. With this improvement, the boards would be expected to provide a better printing surface. Tearing resistance and folding endurance decreased in proportion to the amount of short-fiber pulp present in the board.

When the two-ply sheet containing 25 percent oak pulp (all present in the top ply) is compared with the single-ply sheet having the same amount of oak in the furnish, the folding endurance, ring crush strength, and tension properties were better with the two-ply composite. The burst and tear were comparable.

Combined Board Properties

Tables 2 and 3 show the burst values of the linerboard and combined board. Using the appropriate Uniform Freight Classification (UFC) burst requirements of 1,380 kPa (200 points) for combined board and 690 kPa (100 points) for linerboard as an indication of acceptability, one sees that at least 25 percent oak substitution could be tolerated

Table 4.—Top-to-bottom compression of containers made with oak-pine linerboards[1] [2]

Combined board No.	Linerboard content		Within deformation of 12.7 mm								Within deformation of 25.4 mm							
			23° C, 50 percent relative humidity				27° C, 90 percent relative humidity				23° C, 50 percent relative humidity				27° C, 90 percent relative humidity			
	Oak	Pine	Maximum load[3]	COV[4]	Deformation at maximum load	COV	Maximum load	COV	Deformation at maximum load	COV	Maximum load	COV	Deformation at maximum load	COV	Maximum load	COV	Deformation at maximum load	COV
	— Pct —		MN	Pct	mm	Pct	MN	Pct	mm	Pct	MN	Pct	mm	Pct	MN	Pct	mm	Pct
SINGLE-PLY LINERBOARDS																		
678	0	100	2.50	7.4	9.9	26.6	1.41	5.8	9.1	29.6	3.08	7.4	21.3	13.4	1.51	5.4	14.5	42.3
705	25	75	2.21	7.6	11.4	23.4	1.17	8.7	9.4	50.0	3.32	5.7	23.9	5.0	1.48	6.6	18.0	18.6
679	50	50	2.63	5.3	11.9	7.3	1.56	4.5	11.4	23.0	3.52	7.2	3	10.7	1.64	4.6	17.5	18.5
680	75	75	2.65	8.6	11.7	12.1	1.55	4.4	10.2	19.5	3.44	9.2	20.1	14.9	1.67	4.1	16.5	28.7
681	100	0	2.85	8.0	12.7	1.8	1.53	6.1	11.9	12.1	3.34	6.4	17.5	14.0	1.65	8.6	16.5	25.9
TWO-PLY LINERBOARD																		
682[5]	25	75	2.59	7.6	10.9	26.9	1.54	6.9	10.7	18.6	3.54	6.4	22.4	13.4	1.64	5.1	16.2	35.0

[1] Containers were 273 mm by 205 mm in perimeter by 200 mm high; staple closure.
[2] See Appendix I for English unit equivalents.
[3] Maximum load prior to deformation limit indicated in heading.
[4] COV = coefficient of variation.
[5] Oak only in top ply; pine only in bottom ply.

based on combined board whereas 75 percent oak substitution is satisfactory based on linerboard. The combined board burst values for boards having a low oak content (0-25 pct) were at least double those of the corresponding linerboards, the typical situation. However, as the oak content reached and exceeded 50 percent, the combined board burst was less than double that of the linerboard burst. Further burst testing evaluations and examination of both the boards for pressure roll cutting and the burst equipment indicated that the data were correct and that possibly the mechanism of failure in the burst test changes with the addition of hardwood. Pin adhesion and flat-crush values were satisfactory and comparable for all combinations (table 3).

Box Performance

Compression Table 4 and figure 1 give the top-to-bottom box compression data for two ranges of box deformations, maximum compressive strength within 12.7-mm (1/2-in.) deformation and maximum compressive strength within 25.4-mm (1-in.) deformation. Any maximum compression values experienced beyond the 25.4-mm (1-in.) deformation limit are considered to be irrelevant as the deformation would be excessive for a 200-mm (8-in.)-high box.

The box compressive strength improved with the addition of oak, generally reaching a maximum at

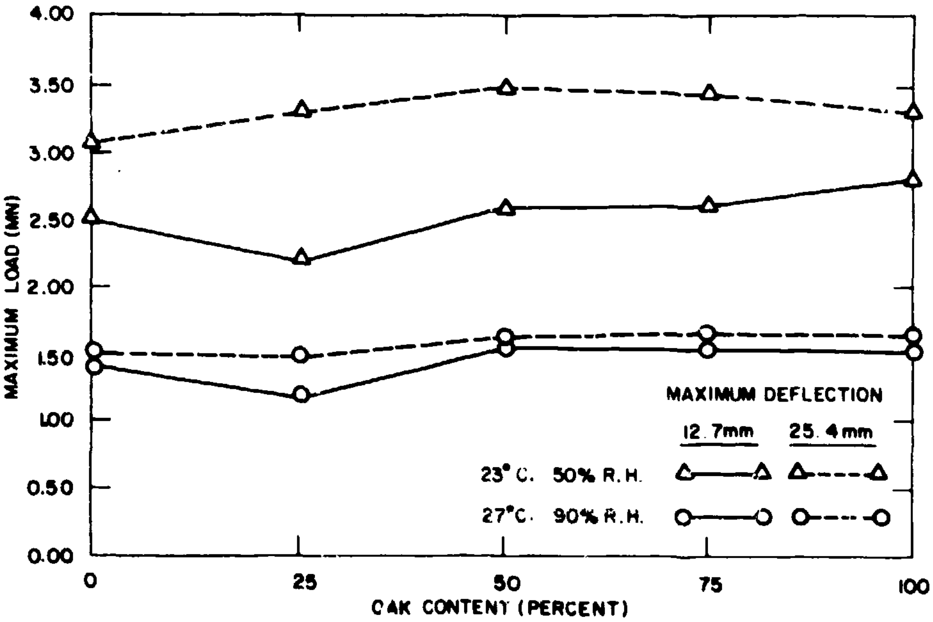

Figure 1.--Top-to-bottom compressive strength of containers. *(M 149 423)*

Table 5.—Scoring effects on combined boards and containers made with oak-pine linerboards

Combined board No.	Linerboard content: Oak	Linerboard content: Pine	Scorewheel[1] clearance ratio	Scoreline fracturing[2] (scoring conditions): 27° C 30 percent relative humidity	23° C 50 percent relative humidity	27° C 90 percent relative humidity	Box edge fracturing[3] (scoring conditions): 27° C 30 percent relative humidity	23° C 50 percent relative humidity	27° C 90 percent relative humidity	Impact resistance[4] (scoring conditions): 27° C 30 percent relative humidity	23° C 50 percent relative humidity	27° C 90 percent relative humidity
	Pct	Pct		Pct	Pct	Pct	Pct	Pct	Pct	m	m	m
				SINGLE-PLY LINERBOARDS								
678	0	100	1.000	—	0	0	—	0	0	—	2.39	2.44
			1.226	11.1	0	—	0.9	0	—	2.36	2.49	—
			1.500	0	0	0	0	0	0	1.83	2.41	2.13
			1.677	0	—	0	0	—	0	2.39	—	2.49
705	25	75	1.000	—	0	0	—	—	—	—	1.93	2.46
			1.226	3.7	0	—	—	—	—	2.03	2.08	—
			1.500	0	0	0	—	—	—	2.34	2.08	2.5'
			1.677	0	—	0	—	—	—	2.30	—	2.34
679	50	50	1.000	—	1.8	0	—	0	0	—	2.08	2.18
			1.226	2.7	0	—	0	0	—	2.03	2.24	—
			1.500	0	0	0	0	0	0	2.16	2.41	2.31
			1.677	0	—	0	0	—	0	1.93	—	2.51
680	75	25	1.000	—	20.2	0	—	19.8	0	—	1.65	1.78
			1.226	16.8	3.7	—	0	0	—	1.93	1.57	—
			1.500	0	0	0	0	0	0	1.75	1.70	1.78
			1.677	0	—	0	0	—	0	2.21	—	2.46
681	100	0	1.000	—	58.0	0	—	51.0	0	—	1.27	1.42
			1.226	40.5	15.7	—	25.7	4.7	—	1.32	1.27	—
			1.500	2.8	4.6	0	0	0	0	1.63	1.50	1.42
			1.677	0	—	0	0	—	0	1.47	—	2.01
				TWO-PLY LINERBOARD								
682[5]	25	75	1.000	—	0	0	—	0	0	—	2.11	2.46
			1.226	1.0	0	—	0	0	—	1.85	2.26	—
			1.500	0	0	0	0	0	0	2.18	2.29	2.36
			1.677	0	—	0	0	—	0	2.39	—	2.46

[1] Scorewheel total clearance divided by combined thickness of board components. In this case the combined thickness equalled 0.78 mm.
[2] Conditions listed are for boards equilibrated at these humidities, then scored. Evaluation was at 23° C, 50 percent relative humidity. Scoring parallel to flutes only—no fracturing noted when scores were made perpendicular to flutes.
[3] For fracturing of panel scores only—no flap failures noted.
[4] Single drop of container having twelve 454 g can loads; 15 boxes dropped/reported value; conditions listed are board conditions at time of scoring, not drop conditions. See footnote 2.
[5] Oak only in top ply; pine only in bottom ply.

about 50 percent. With the 100 percent oak linerboard, boxes still had compression values above those for the pine control. While boxes humidified to a higher moisture content decreased overall in compression resistance, the oak-containing linerboards still performed better than the all-pine boards.

The two-ply linerboard showed a considerable increase over its single-ply counterpart (board 705) and was on par with the maximum achieved with 50 percent oak. The cause of the difference is unknown; however, board 705 was combined at a later date than the rest of the boards.

No correlation seemed evident when comparing box compression to combined board burst. Despite the continuously decreasing burst value for the combined boards, compression always remained above the level found for the control, with the exception of board 705 (25 pct oak) (see table 4). Nor did either the short column or flexural stiffness, properties used to predict compression *(10)*, correlate with burst (table 3).

Box Scoreline Fracturing Fracturing is defined as the breaking and separation of the components of corrugated board along the folds during box setup, and will occur in a box as either vertical edge fracture or horizontal flap fracture. Normally, fracture occurs as vertical edge fracture of the outer liner. In this study no flap fracture occurred. Nor was there any fracturing of the interior vertical linerboards or of the medium.

Edge fracturing was measured on those boxes prepared for impact

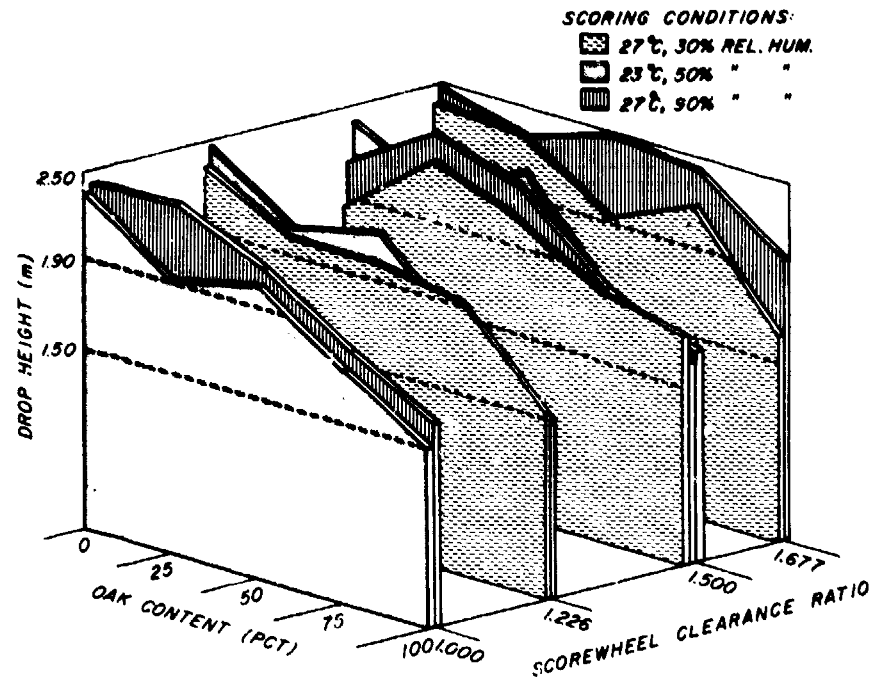

Figure 2.—Effect of oak content, scorewheel clearance ratio, and moisture content on impact failure drop heights. *(M 149 152)*

testing, with the results given in table 5 as a percentage of total exterior length. Actual edge fracturing on the boxes was less than experienced in the visual scoring evaluation, that is the scoring and folding of sheetstock test specimens. Any scoring condition yielding less than 10 percent visual fracturing (table 5) gave no detectable edge fracturing in the boxes.

The results of the visual scoring tests showed that with proper moisture content in the boards and a sufficiently open set of scorewheels, any amount of oak can be included in the linerboard without having the linerboards fracture during box setup.

Impact (Drop) Despite some inconsistencies in the data (table 5), certain trends can be seen. Impact heights were generally higher for the corrugated boards scored at higher moisture contents. Above 50 percent oak content the impact heights decreased with increasing oak levels, but, in the lower range of oak contents (below 50 pct) there seemed to be negligible decreases in drop height relative to increases in oak content.

For greater scorewheel clearances, more oak could be tolerated before the drop height started to decrease. As the scorewheel clearance decreased, lower values of drop height were experienced at a given oak content. These variations become more evident in figure 2, which was constructed from the data in table 5.

While the effects of these variables need to be noted, an important overall result needs to be pointed out; while the severest drop level called for by the proposed ASTM performance standard *(1)* is 1.2 m (48 in.), all of the impact heights were equal to or in excess of 1.3 m (50 in.) for those conditions examined. Even with a 1.9-m (75-in.) minimum acceptable drop height, up to 50 percent oak could be included in the linerboard before visual fracturing and box edge fracturing would cause a problem.

Conclusions

The results indicate that considerably more hardwood can be used in linerboard than is presently being used commercially. With separate pulping and refining of pine and oak, up to 25 percent can be used in linerboard furnishes to produce satisfactory boxes and still satisfy today's required carrier rules. Even oak levels greater than 50 percent can be used and still provide boxes with satisfactory compressive strength, but the bursting strength may be insufficient to fully meet existing rules. While scoring problems were observed with the linerboards having a higher percentage of oak when scoring was done at low moisture, these could be eliminated by introducing a higher moisture level in boards and proper selection of scorewheel clearance.

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Appendix I

English Equivalents for Tables 2 to 4

Table 2a.—Physical properties of oak-pine linerboards[1]

Machine run No.	Linerboard content: Oak	Linerboard content: Pine	Basis weight	Density	Burst	Tear: Machine direction	Tear: Cross-machine direction	Tensile strength: Machine direction	Tensile strength: Cross-machine direction	Tensile modulus of elasticity: Machine direction	Tensile modulus of elasticity: Cross machine direction	Folds: Machine direction	Folds: Cross-machine direction	Ring crush: Machine direction	Ring crush: Cross-machine direction
	Pct	Pct	Lb/1,000	G/cm³	Points	G	G	Lb/in.²	Lb/in.²	1,000 lb/in.²	1,000 lb/in.²	Double folds	Double folds	Lb	Lb
				ft²											
SINGLE-PLY LINERBOARDS															
7210	0	100	42.4	0.64	102.1	342	363	7,408	3,585	682	342	1,616	953	128	101
7211	25	75	42.1	0.66	105.2	327	349	6,945	3,820	730	365	1,225	762	121	93
7212	50	50	42.0	0.68	107.8	299	305	7,318	3,870	702	376	1,011	753	122	94
7215	75	25	42.0	0.69	105.5	258	285	7,113	4,226	831	439	560	480	128	94
7213	100	0	42.0	0.69	87.0	196	210	6,253	3,715	746	400	201	92	101	84
TWO-PLY LINERBOARD															
7214[1]	25	75	42.5	0.68	102.6	314	364	7,674	4,265	795	386	1,434	1,102	129	103

[1] Oak only in top ply, pine only in bottom ply.

Table 3a.—Physical properties of the combined board[1]

Combined[2] board No.	Linerboard content: Oak	Linerboard content: Pine	Basis weight		Burst		Flat crush		Pin adhesion: Single-face side		Pin adhesion: Double-back side		Short column compression: 80° F, 30 percent relative humidity		Short column compression: 73° F, 50 percent relative humidity		Short column compression: 80° F, 90 percent relative humidity		Flexural stiffness[3]: Parallel-to-length		Flexural stiffness[3]: Perpendicular to length	
	— Pct —		Lb/1,000 ft²	COV[4]	Points	COV	$Lb/in.^2$	COV	Lb/in.	COV	Lb/in.	COV	Lb/in.	COV	Lb/in.	COV	Lb/in.	COV	Lb/in.	COV	Lb/in.	COV
											SINGLE-PLY LINERBOARDS											
678	0	100	127.2	0.8	219	9.4	27.0	6.3	3.94	5.3	4.58	7.6	61.0	7.0	54.0	5.7	26.2	3.1	105	4.4	182	8.6
705	25	75	128.0	0.6	218	6.9	29.7	3.7	3.81	8.5	4.58	5.1	59.8	4.3	56.3	6.7	23.0	4.2	114	5.2	204	8.2
679	50	50	124.2	0.6	195	9.1	27.0	3.2	3.90	5.4	4.96	4.7	60.5	4.2	53.9	5.8	26.2	1.8	111	6.5	225	14.3
680	75	25	123.8	0.9	185	5.5	26.6	6.8	3.82	6.2	4.82	7.9	60.2	1.8	54.6	5.6	27.0	3.2	117	3.7	224	13.7
681	100	0	122.8	1.1	148	8.8	27.8	3.2	3.79	2.9	4.41	6.8	55.8	2.6	49.8	5.3	25.5	2.8	113	6.0	214	18.8
											TWO-PLY LINERBOARD											
682[5]	25	75	131.5	1.2	224	8.4	27.7	3.7	4.01	6.1	4.82	9.5	66.5	4.0	57.2	7.0	28.5	3.3	117	4.1	208	12.6

[1] All boards conditioned and tested at 73° F, 50 pct relative humidity except where noted.
[2] All mediums were commercial 26 lb/1,000 ft² NSSC board.
[3] Four-point bending; flutes parallel or perpendicular to sample length; 5 samples singleface up, and 5 samples singleface down.
[4] Cofficient of variation [=] percent.
[5] Oak only in top ply, pine only in bottom ply.

Table 4a.—Top-to-bottom compression of containers made with oak-pine linerboards [1,2]

Combined board No.	Linerboard content: Oak	Linerboard content: Pine	Within deformation of 1/2 inch, 73° F, 50 percent relative humidity: Maximum load[2]	COV[3]	Deformation at maximum load	COV	Within deformation of 1/2 inch, 80° F, 90 percent relative humidity: Maximum load	COV	Deformation at maximum load	COV	Within deformation of 1 inch, 73° F, 50 percent relative humidity: Maximum load	COV	Deformation at maximum load	COV	Within deformation of 1 inch, 80° F, 90 percent relative humidity: Maximum load	COV	Deformation at maximum load	COV
	Pct		Lb	Pct	In.	Pct	Lb	Pct	In.	Pct	Lb	Pct	In.	Pct	Lb	Pct	In.	Pct
								SINGLE-PLY LINERBOARDS										
678	0	100	561	7.4	0.39	26.6	318	5.8	0.36	29.6	692	7.4	0.84	13.4	340	5.4	0.57	42.3
705	25	75	497	7.6	0.45	23.4	264	8.7	0.37	50.0	747	5.7	0.94	5.0	333	6.6	0.71	18.6
679	50	50	591	5.3	0.47	7.3	350	4.5	0.45	23.0	792	7.2	0.84	10.7	369	4.6	0.69	18.5
680	75	25	596	8.6	0.46	12.1	348	4.4	0.40	19.5	774	9.2	0.79	14.9	376	4.1	0.65	28.7
681	100	0	640	8.0	0.50	1.8	345	6.1	0.47	12.1	752	6.4	0.69	14.0	372	8.6	0.65	25.9
								TWO-PLY LINERBOARD										
682[4]	25	75	583	7.6	0.43	26.9	347	6.9	0.42	18.6	796	6.4	0.88	13.4	370	5.1	0.64	35.0

[1] Containers were 10.75 in. by 8.06 in. in perimeter by 8 inches high; staple closure.
[2] Maximum load prior to deformation limit indicated in heading.
[3] Coefficient of variation.
[4] Oak only in top ply; pine only in bottom ply.

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Use of oak in linerboards, by D. W. Bormett, D. J. Fahey, and J. F. Laundrie, Madison, Wis., FPL. 9 p. (USDA For. Serv. Res. Pap. FPL 410).

Oak and pine pulps in varying ratios were investigated for linerboard use in corrugated containers. It was found that at least 25 percent oak could be included and still satisfy today's required carrier rules. Scoreline fracturing for boards of any oak-pine ratio can be eliminated by proper adjustment of scorewheel clearance and board moisture content.